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OPTICAL TRANSMISSION SYSTEM USING COHERENT OPTICAL TIME DOMAIN REFLECTOMETRY

Background of the Invention

The present invention concerns an amplified and non-bi-directional fiber optic link with optical amplifier loopback to enable COTDR. It also concerns a method of reducing interaction between the signal in one transmission direction and backscattered noise from the other transmission direction in a link of the above kind.

The invention concerns coherent optical time domain reflectometry (COTDR), a technique which is used to monitor the quality of optical links.

For COTDR to be used in non-bi-directional optical transmission systems with repeaters, the repeaters must be looped to enable the reflectometry signal used to be transmitted; the amplifiers of the repeaters include isolators blocking transmission of the reflected OTDR signal. A COTDR measurement arrangement of the above kind in a non-bi-directional transmission system with amplifiers is described, for example, in an article by S. Fukurawa *et al.* "Enhanced coherent OTDR for long span optical transmission lines containing optical fiber amplifiers", IEEE Photonics Technology Letters, 1995, vol. 7, no.5, pp. 540-542.

R.K. Staubli *et al.*, in "Crosstalk penalties due to coherent Rayleigh noise in bi-directional optical communication systems", Journal of Lightwave Technology, 1991, vol. 9, no.3, describe the effects in bi-directional transmission systems of beating between the signal propagating in one direction and noise generated by Rayleigh backscattering of the signal propagating in the other direction. The document does not refer to non-bi-directional systems. It specifies that in bi-directional systems with dual sources and with different wavelengths in the two propagation directions there is no detectable interference between the backscattered Rayleigh light and the signal. The limit due to the effects of beating is evaluated for bi-directional

systems with a single source, but no practical solution is proposed for exceeding the limit.

O. Gautheron *et al.*, in "COTDR performance optimization for amplified transmission systems", IEEE Photonics Technology Letters, 1997, vol. 7, no. 5, pp. 1041-1043, described two types of amplifier loopback for non-bi-directional transmission systems; they also describe the impact of coherent Rayleigh noise on system performance when the same wavelengths are used for both transmission directions. To reduce this impact, the article proposes to provide high-speed polarization scrambling in the transmission system and to limit the transmitter power at each wavelength to +2 dBm.

Summary of the Invention

The invention proposes a solution to the problem of beating between a signal propagating in one direction and Rayleigh backscattering of the signal propagating in the other direction for a non-bi-directional amplified optical transmission system with repeater loopback. The solution in accordance with the invention limits or eliminates the effect of such beating by simple means. It enables the power limit of prior art solutions to be exceeded.

To be more precise, the invention proposes an amplified and non-bi-directional fiber optic link including optical loopback of the amplifiers to enable COTDR, characterized by different wavelengths in the two transmission directions.

The invention also proposes a method of reducing interaction between the signal in one transmission direction and backscattered noise originating from the other transmission direction in an amplified and non-bi-directional fiber optic link including optical loopback of the amplifiers to enable COTDR, characterized by the use of different wavelengths in the two transmission directions.

In the above link or method, the wavelengths in the two transmission directions are advantageously chosen so

that the backscattered signal originating from the signal in one transmission direction is strongly attenuated on passing through the receive filter of a channel in the other transmission direction.

In the above link or method, the wavelengths in the two transmission directions can be chosen so that the backscattered signal originating from the signal in one transmission direction is attenuated by a factor of at least 10 on passing through the receive filter of a channel in the other transmission direction.

When a wavelength division multiplex is sent in each transmission direction, the wavelengths of the multiplex in one transmission direction are interleaved between the wavelengths of the multiplex in the other transmission direction.

The invention further proposes an amplified and non-bi-directional fiber optic link including optical loopback of the amplifiers to enable COTDR, characterized by means for widening the spectrum of the signal in at least one transmission direction.

In one embodiment, the spectrum widening means comprise wavelength modulation means. The wavelength modulation means advantageously effect wavelength modulation with a modulation rate in the range from 0.5 kHz to 10 GHz, preferably in the range from 1 kHz to 5 GHz. The wavelength modulation means preferably vary the wavelength over a range greater than a few times the bit rate of the link, preferably greater than twice the bit rate of the link.

In one embodiment, the spectrum widening means comprise means for modulating the injection current of a laser of a sender of at least one transmission direction.

In another embodiment, the spectrum widening means comprise phase modulation means. The phase modulation means advantageously effect modulation at a modulation rate greater than a few times the bit rate of the link, preferably greater than twice the bit rate of the link.

The invention finally proposes a method of reducing interaction between the signal in one transmission direction and backscattered noise originating from the other transmission direction in an amplified and non-bi-directional fiber optic link including optical loopback of the amplifiers to enable COTDR, characterized by widening of the spectrum of the signal in at least one transmission direction.

In one embodiment, the spectrum is widened by wavelength modulation, for example with a modulation rate in the range from 0.5 kHz to 10 GHz, preferably in the range from 1 kHz to 5 GHz. The wavelength modulation can vary the wavelength over a range greater than a few times the bit rate of the link, preferably greater than twice the bit rate of the link.

The spectrum is preferably widened by modulating the injection current of a laser of a sender of at least one transmission direction.

In another embodiment, the spectrum is widened by phase modulation, for example with a modulation rate greater than a few times the bit rate of the link, preferably greater than twice the bit rate of the link.

Brief Description of the Drawings

Other features and advantages of the invention will become apparent on reading the following description of embodiments of the invention given by way of example and with reference to the appended drawings, in which:

- Figure 1 is a diagrammatic representation of a non-bi-directional amplified optical transmission system with loopback between repeaters;

- Figure 2 is a diagrammatic representation of the wavelengths used in the system in accordance with the invention shown in Figure 1.

Detailed Description of the Invention

Figure 1 is a diagrammatic representation of a non-bi-directional amplified optical transmission system with loopback between repeaters. The Figure 1 system comprises an upstream fiber 1 and a downstream fiber 2. Upstream and downstream senders 3 and 4 send signals in

fibers 1 and 2, respectively. Upstream and downstream receivers 5 and 6, at the other end of fibers 1 and 2, receive the corresponding signals. An upstream COTDR device 8 at the same end as the upstream sender and the downstream receiver sends signals in fiber 1 and receives signals from fiber 2. A downstream COTDR device 9 at the same end as the downstream sender and the upstream receiver sends signals in fiber 2 and receive signals from fiber 1.

Figure 1 shows two repeaters 10 and 11 in the possible optical loopback configurations. Each of the repeaters 10 and 11 comprises an upstream optical amplifier 13 and 15 and a downstream optical amplifier 14 and 16 on the upstream and downstream fibers 1 and 2, respectively. The repeater 10 has two loopback fibers 18 and 19 which respectively connect the input of the upstream amplifier 13 to the output of the downstream amplifier 14 and the output of the upstream amplifier 13 to the input of the downstream amplifier 14. The repeater 11 has a loopback fiber 21 which connects the output of the upstream amplifier 15 to the output of the downstream amplifier 16. The loopback fibers 18, 19 and 21 enable the reflected COTDR signal to reach the COTDR device from which it originated. A system like that shown in Figure 1 is described in the previously mentioned article by O. Gautheron *et al.*

In a system of the above kind, the power backscattered by the Rayleigh effect in the upstream fiber is transmitted in the downstream fiber 2 and represents a transmission penalty. A first embodiment of the invention proposes to reduce the transmission penalty by using different wavelengths in the two transmission directions to reduce or eliminate in the receive window(s) of one transmission direction backscattered power originating from the other transmission direction. The difference in wavelength between the two transmission directions is preferably greater than the drift of the

senders, for example greater than the drift of the lasers used as senders. A difference of 0.4 nm or 0.5 nm may be sufficient. In the case of wavelength division multiplexing (WDM), the wavelengths in the two transmission directions are advantageously offset to interleave the channels. Figure 2 shows the possible shapes of the spectra in one of the two transmission directions. The transmission channels are represented by the vertical lines 25 and 26. The dashed line rectangles 27 and 28 represent the corresponding receive windows. The continuous line rectangles 29 and 30 represent backscattered noise from the other transmission direction.

In transmission of the type shown in Figure 1, with DSF fibers or standard fibers, it is therefore possible to use channels at wavelengths λ_1 and λ_3 of 1 550 nm and 1 552 nm in the upstream direction and channels at wavelengths λ_2 and λ_4 of 1 551 nm and 1 553 nm in the downstream direction. With this type of wavelength allocation, 0.5 nm receive windows can be provided for each channel. A configuration of this kind strongly attenuates the backscattered signal from one transmission direction on passing through the receive filter of channels of the other transmission direction. An attenuation factor of at least 10, i.e. reduction of the backscattered signal to less than 10% of its initial power, gives good results. This is a simple way to limit the penalties arising from interaction with the backscattered signal.

The invention therefore allows optimum use of the transmission system, despite optical loopback at the amplifiers, whilst assuring effective transmission of the COTDR signals.

A second embodiment of the invention proposes to reduce interaction between the signal in one transmission direction and the backscattered noise originating from the other transmission direction even more, by widening

the spectrum of the signal in at least one transmission direction. This widens in corresponding fashion the spectrum of the Rayleigh backscattered signal; the effect of beating with the signal in the other transmission direction is then reduced in the receive window of that other transmission direction.

The spectral widening can be done on the signal in one transmission direction. It is also possible to use spectral widening for both transmission directions, although this is not essential for achieving the results of the invention.

The spectral widening can be obtained by modulating the wavelength of the emitted signal, for example. The modulation frequency is advantageously in the range from a few kHz to a few GHz, for example in the range from 0.5 kHz to 10 GHz. The modulation rate is typically greater than a few times the bit rate of the link, preferably greater than twice the bit rate of the link. A modulation rate of a few GHz, for example 5 GHz or 10 GHz, is appropriate in the case of a 2.5 Gbit/s link. In the case of a WDM (wavelength division multiplex) link, the bit rate of the link refers to the bit rate of each channel.

Wavelength modulation of the above kind can be effected simply by modulating the injection current of a laser serving as the light source in a sender of the transmission system. This solution is particularly advantageous in the case of wavelength modulation at low frequencies, typically below a few kHz or 1 kHz; in this case spurious intensity modulation generated by wavelength modulation of the laser is absorbed or smoothed by the post-amplifier of the sender, if it has one.

In other cases the spurious intensity modulation may be perfectly acceptable and not seriously degrade link performance. It is also possible to use multiple section lasers as senders. Modulating the injection current of

one section of the laser can modulate the wavelength of the signal without spurious modulation of the intensity of the signal. Wavelength modulation at high rates, for example at rates of 1 GHz or a few GHz, attenuates beating between the backscattered signal and the signal propagating in the other transmission direction, at least in the receive windows of that other transmission direction.

Another embodiment of the invention phase modulates the signal at a high rate in at least one transmission direction. Interaction between the signal reflected by Rayleigh backscattering and the signal propagating in the other transmission direction is then less of a problem. This solution has the advantage of not producing any spurious intensity modulation.

This solution can be used by providing downstream of the sender 3 or 4 a phase modulator with a modulation rate greater than a few times the bit rate of the link, for example greater than twice the bit rate of the link. A modulation rate in the range from 5 GHz to 10 GHz is appropriate for a 2.5 Gbit/s link. Once again, in the case of a WDM link, the link bit rate means the bit rate for each channel. The modulation angle is immaterial, and can be chosen between 0 and 2π. A value of π gives good results.

Of course, the present invention is not limited to the examples and embodiments shown and is open to many variants that will suggest themselves to the skilled person. Modulation means other than those described can be used, for example.